INVESTIGATION OF MITIGATION OF VIBRATIONS IN GEAR SYSTEM THROUGH PARTICLE DAMPING: Review

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Abstract: Usually a gear engagement generates more vibrations in the system and it is a main reason behind the noise under the heavy load and speed. To suppress these vibration the particle damping technology is considered in this paper. The particle damper is inserted in the inherent holes on the periphery of gear, it is nothing but the one type of passive method to reduce the vibrations. The particle damping is all about adding some auxiliary mass to the system. By means of this the inelastic collisions occur in the gear transmission in order to dissipate the energy into gear transmission. With the usage of dynamic analysis, various boundary condition of centrifugal field of the gear transmission are obtained in this paper. Subsequently discrete element method is employed to examine the dynamics and kinematics of those particles and also the relation between the surface roughness (i.e. coefficient of friction) and energy dissipation at various load and speed are arrived at. Later through simulation it is observed that smoother particle offers better damping effect at low rotational speed, while rougher particle shows good damping effect with high speed. Finally all the simulating results are compared with experiments so as to offer theoretical framework to the practical observations.

***Index Terms* – Gear system, Particle damping, vibration analyses.**

I. INTRODUCTION

Gears are the important part which is widely used in industry and other purpose [3], Due to its characteristics like continuous speed ratio, greater efficiency and tight structure [7]. The industry demands smoother and more efficient gear transmission, for this purpose researchers took continuous efforts on to minimizes the vibrations in the structure[3].The mesh stiffness according to various time period is the main cause of noise and vibration, it adversely affect the machinery and it will lead to damage and reduce the life of machinery[1-4]. Hence, minimize or suppress those vibration and noise will improve the reliability and life of machine. There are several methods like active and passive method to suppress the vibration and noise. Passive method has a greater advantage over the active method because by means of active method a little amount of vibration can be suppress but it will lead to greater change in actual dimensions of structure and it increases overall manufacturing cost, calculations and design.[11-13]. In case of passive vibration suppression method with the help of energy consuming equipment's the energy can be partly dissipated from the gear transmission and it will reduce the vibration and noise[12].

A review of one of the passive vibration suppression method named as particle damping is introduced in this paper. The small particles of steel balls are used as the damping media. This particles are placed into the cavities of the machines, this damping particles experiences the inelastic collision and friction which cause to reduce or suppress the vibration and noise [14,15]. This technology provides advantages like a high damping effect, resist high temperature and most important is a little changes in original structure and very less amount of mass to be add to structure. Now a days, the technology is widely used for vibration suppression, though this technology is used in many application it is not thoroughly studied in the field of gear transmission[1,4,19].Particle dampers are consisting of small granular particles made up of metal or ceramics which are enclosed in hollow container, this container is attached to vibrating structure or placed into the cavities of structure[8,9].This particles are freely moving inside the container and vibrating energy are effectively dissipate among particles and collision between container wall and particle[19].

To analyse the dynamics and kinematic of the particles the discrete element method is being used which is proposed by cundall and atrackz in 1979, which is different from continuum calculation method and particulate matter are based on newton's second law instead of minimum potential energy principle. In discrete element method the contact force is calculating by overlap of contact particle and it will update movement and position of every particle with respect to time period [1-4]. The damping effect of particles are affected by many factors like material and diameter of particles, coefficient of friction and restitution coefficient of particles and filling rate if the damper [21, 22].The tangential that is friction energy dissipation is directly affected by coefficient of friction while on other hand normal (i.e. collision) energy dissipation is affect indirectly, and these both have great influence on total energy dissipation [1].

Discrete element model description:

Gear Model

The lightning holes are drilled on the web of gears and we attached particles or containers into that inherent holes as shown in figure 1[1]. As the gear rotates about its 'X' axis the vibrations are generates and transferred from one part to another with sequential manner. At the start the vibration is observed at tooth surface and then it follow the path like lightening holes--axle--bearing--pedestal--gearbox respectively[18]. And with the rotation of gears the damping particles are also start to move, resulting friction and collision with damper wall and among each other, and due to centrifugal force the particle will move towards the damper wall. We know that the relationship between rotational speed and natural frequency, change in rotational speed will cause to change the natural frequency of the gear system, and the equivalent mass is nothing but the function of natural frequency hence the equivalent mass is also the function of rotational speed[1,4].

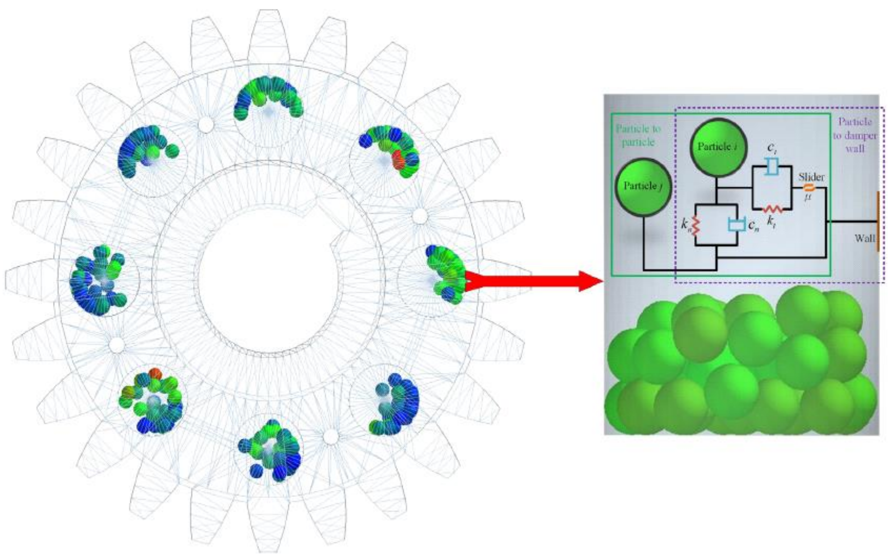

Figure 1.Particle Damper Placed Into Gear [4].

All above parameter of gear system like equivalent mass, equivalent damping coefficient and stiffness coefficient are changes according to rotational speed and rotational load and it show different energy dissipation nature of the particle damper at various condition. So we need to know about hoe these parameter changes according to various conditions [21].

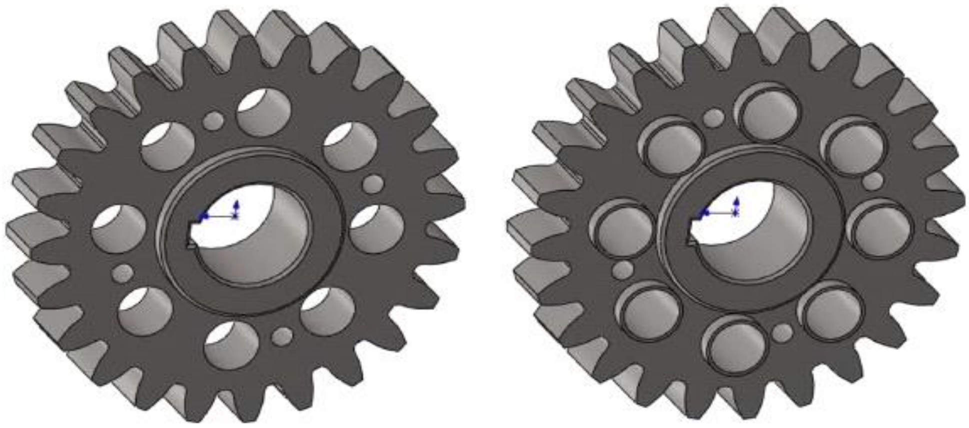

Figure 2.Diagram Of Driven And Driving Gear[1].

Model for dynamic analysis:

The constructional detail of the system used for the dynamics analysis is shown in figure 3. In this analysis damping particles are not included, it only investigate the dynamics and kinematics of gear pair under meshing[3]. The driven and driving gear are mounted on spline shaft and it only rotate about only 'z-axis. toanalyse the behaviour of energy dissipation of particle damper, for this reason we need to know about the dynamics of gear under actual working condition. This dynamics are analyse at various rotational speed and rotational load and it will shows the various behaviour of energy dissipationaccording to working condition.[1,4].

To carried out analysis rotation speed is set as 100rpm, 300rpm, 500rpm,1100rpm and for every speed set various torque as 2, 4, 8, 16 (N-m) with 1st, 2nd, 3rd, 4th load[1]. Set the driven gear at 600 rpm with 2 N-m torque i.e. rotational load. The figure 4 shows dynamic speed response and figure 5 shows acceleration-frequency response after that took these response as input condition for DEM analysis and find out dynamic response and response of energy dissipation of particle damper[4].

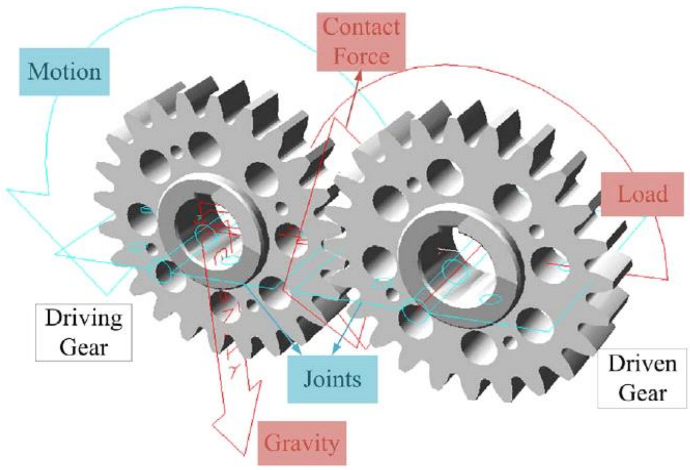

Figure 3.Gear Model For Dynamic Analysis[1].

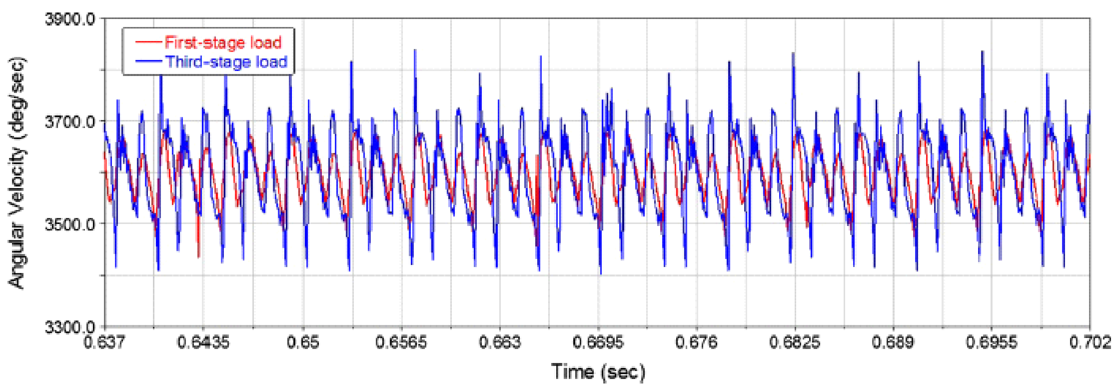

Figure 4. Dynamic Speed Response Of Driven Gear Under 1st And 3rd Stage Load[4].

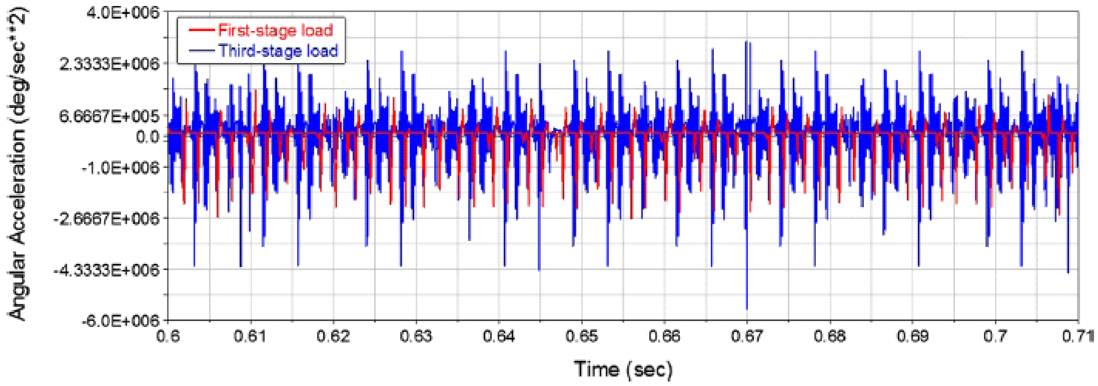

Figure 5. Dynamic Acceleration Response Of Driven Gear Under 1st And 3rd Stage Load[4].

Discrete element method:

In this method we used the dynamic response or parameter obtain from analysis of gear pair with actual working condition and having meshing with each other are carried for the DEM analysis of particle damper. To obtain the relationship between rule of energy dissipation with respect to the friction coefficient is the main objective of this analysis so to obtain that we maintain constant value of friction coefficient and 3 mm particle made up of stainless steel is used.

Rule of energy dissipation with rotational speed:

The intensity of centrifugal force changes accordingly with rotation of speed. The particle have different movement in different centrifugal field, and it also affect the behavior of friction and inelastic collision hence we need to point out rule of energy dissipation with different speed [1]. There are two types of energy dissipation one is tangential energy dissipation and other is normal energy dissipation which caused due to friction and collision respectively. Total energy dissipation is termed as sum of tangential and normal energy dissipation [4].Tangential energy dissipation increases with friction coefficient. At the low rotational speed the intensity of centrifugal force is not enough to constraint the particle movement hence tangential energy dissipation is not significant. The energy dissipation is mainly due to collision instead of friction of particles. With the increasing rotational speed the intensity of centrifugal force is more due to the particles clasps with damper wall which is away from axis of rotation and it will increase the rate of tangential energy dissipation. in this case more energy dissipated by means of friction than collision, at certain stage friction coefficient exceeds limit value it will cause stagnant behavior of tangential energy dissipation due to high surface roughness obstruct relative movement between particle. Besides that increase in friction coefficient decreases the normal energy dissipation. simply we can say smoother particle promotes the dissipation rate of inelastic collision energy of damper as they collide and move freely with each other it that conclude high friction coefficient decreases the normal energy dissipation[1,19,4].

Table 1: Energy Dissipation Trend With Coefficient Of Static Friction At Various Rotational Speed.

Rotational speed	Coefficient of static friction	Energy dissipation trend
100 RPM	0.1	Decrease (Optimum)
300 RPM	0.2	Decease
500 RPM	0.3	Increase
700 to 1100 RPM	0.5 or 0.6	Increase

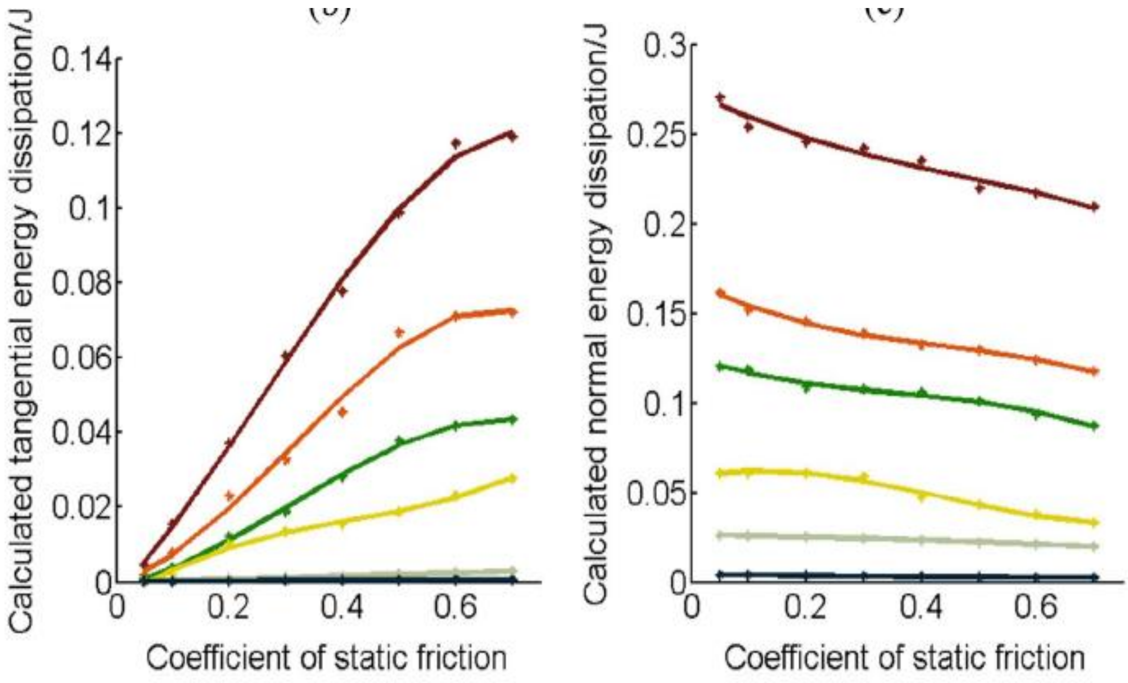

Figure 6. Tangential Energy Dissipation And Normal Energy Dissipation Trend With Rotational Speed [1].

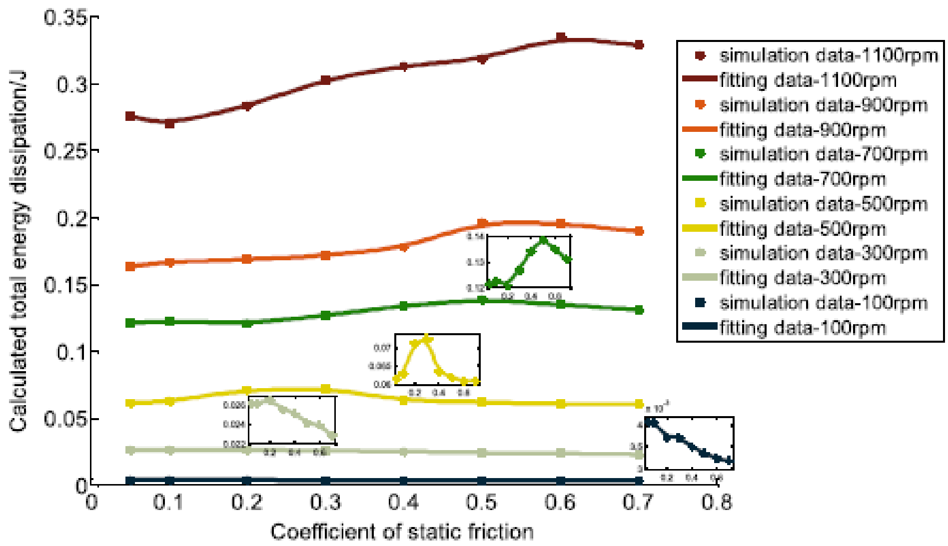

Figure 7. Total Energy Dissipation Trend With Rotational Speed [1].

Rule of energy dissipation with variable load:

Excitation of driven gear changes with variable load. and it will apply different force on particles and this cause different inelastic collision and friction with different particle movement, hence we need to study the energy dissipation rule under variable load for this purpose set 700 RPM as constant speed on driven gear and load varies from 1st to 4th stage Figure shows various behavior of energy dissipation of particle under variable load [1].

The small amount of increment in energy dissipation from 2nd load and there is no increment between 3rd and 4th stage load it shows opposite nature according to rotational speed for all load condition the optimum coefficient value is 0.4-0.5 but it will change in the case of rotational speed to justify such a trend in variable load condition we need to find out normal as well as tangential energy dissipation of damper with various coefficient of static friction and variable load as shown in figure [1, 4].

This cannot shows any relation between tangential energy dissipation and variable load as it shows similar nature but the increasing value of coefficient of static friction the normal energy dissipation starts to decrease with different ranges of load condition, It shows direct influence on normal energy dissipation with various load condition on driven gear and load ultimately affects the collision of particle [1].

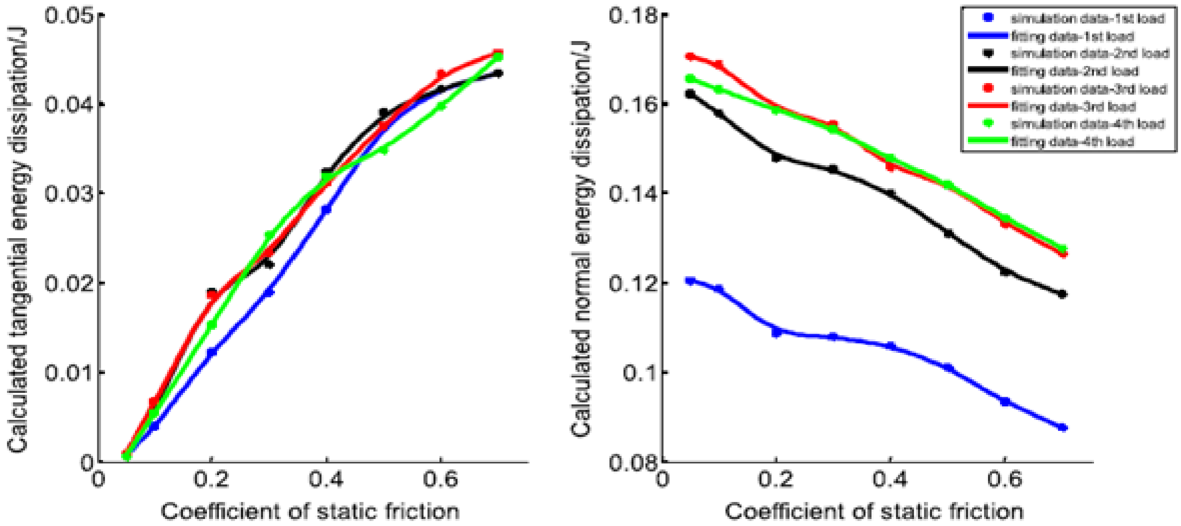

Figure 8. Tangential Energy Dissipation And Normal Energy Dissipation Trend With Various Load [1].

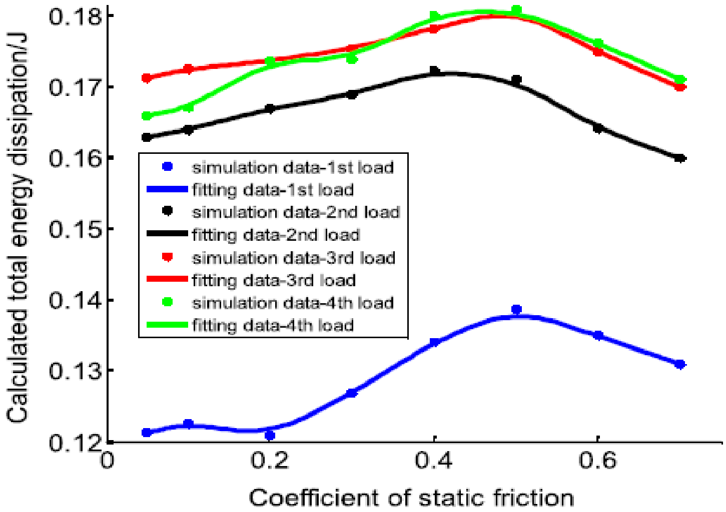

Figure 9. Total Energy Dissipation Trend With Various Load [1].

Experimental Analysis:

The experimental set up consist of torsional shaft, loader, pedestal bearing, gear pair, accelerometer, coupling, torque sensor, receiver and computer with control unit etc. the acceleration value in X, Y and Z direction of gear is collects with the help of acceleration transducer and transfers to receiver [1]. To carried out experimental analysis 3 mm stainless steel ball with 3 kind of surface roughness value used as particle. Accurately grind, rough grind and rough machining are the types of surface roughness of particle. We varies rotational speed of gear from 100 RPM to 1100 RPM with 1stconstant load and filling rate of damper is set at 60% to verify the result obtain from 3.1 and in second case we varies load from 1st stage to 2nd stage with constant speed of 700 RPM to verify result obtain from 3.2 [1, 4].

Below figure shows the tested result of damping effect with variable load and rotational speed. The accurate grinded particle shows the optimum damping effect at low speed and less friction coefficient. Whereas rough grinded and rough machined particles provide better damping effect at middle speed. This experimental results are similar to simulation result of rotational speed [1, 3, 4]. Test with variable load also agree with the simulation results it shows with any kind of surface roughness of particle at 2nd stage load it gives best damping effect and from1st load to 2nd load energy dissipation amplitude reflects its maximum value and vice versa from 2nd to 4th load [4].

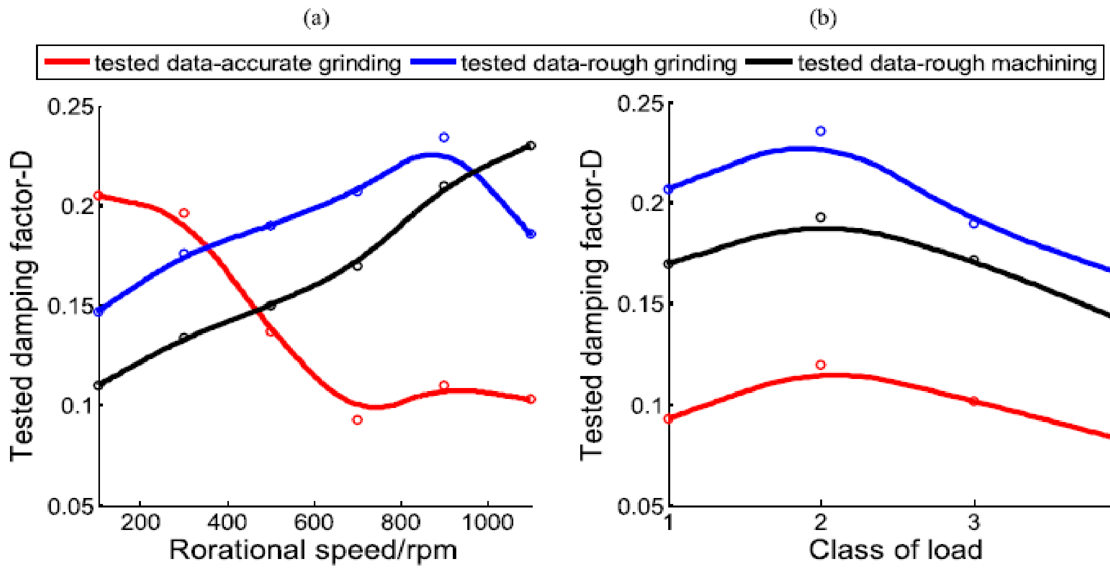

Figure 10. Experimental Results Of Damping Effect: (A) At Rotational Speed (B) At Varied Load [1].

Conclusion:

This paper investigates the damping effect of damper and coefficient of static friction at different load and rotational speed through DEM analysis with experimental justification. Hence it is concluded that particle with coefficient of static friction below 0.2 provides better damping effect below 300 RPM, and relatively at high speed that is above 700 RPM rougher particles provides better damping effect. Best friction coefficient varies with rotational speed that is it increases with increasing rotational speed. While in 2nd case the optimum damping effect observed at 2nd stage load, and damping effect decreases with increasing load.

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